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GEOMORPHIC ASPECTS OF NORMAL AND ACCELERATED EROSION

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Geologic norm of erosion--The twin concepts "normal erosion" and "accelerated erosion," commonly considered to include all erosion past and present, are disarmingly simple. If interpreted literally, they suggest that accelerated erosion was unknown before the coming of man, and, conversely, that the changes brought about by man merely quickened the pace of certain normal processes. Both of these interpretations are misleading.

Realizing that normal erosion was a flexible quantity varying widely with meteorological, tectonic, and other influences, Lowdermilk, in 1929, set up an idealized standard of natural erosion, aptly named the "geologic norm of erosion" [see 6 and 7 of "References" at end of paper]. Erosion was considered in the broadest possible sense and was made to include the mass-movement processes, many of which are highly effective in the natural denudation of the lands.

Transition from the geologic norm of erosion to present-day erosion has involved far more than simple acceleration. Extensive changes of balance in the effectiveness of mass-transport and mass-movement must have taken place. On the natural landscape, streams carved their channels much as they do today, but the percentage of permanently flowing streams was probably larger, and the percentage of ephemeral and intermittent drainages smaller, than now. There was generally a good plant-cover in humid lands and, so far as that covering was complete, slope-washing was prevented. The amount of soil-removal by slope-washing or sheet-erosion must have been small. Owing to good infiltration into deep mellow soils rich in humus, however, mass-movements of soil down slope by creep must have been highly effective. Streams received much of their load from creeping valley slopes, but because of an equable hydrologic regimen resulting from good ground-storage, streams carried their loads with relatively small fluctuations in transporting power.

Despite the rapid destruction brought on by clearing the lands for cultivation, it is evident that soil-erosion is not altogether a new process introduced by man. Very slow erosion of surface soil is an essential pedogenic process, and must have been active long before the first crude tillage of the soil. Under natural conditions, too, local and occasional events temporarily induced serious acceleration of soil-removal. Strokes of lightning in the dry fall forest, devastating blights, uprooting tornadoes, and sudden downpours of tropical cyclones all can penetrate the land's vegetal defense and expose the soil to accelerated erosion.

Interrelation of vegetal cover and soil-profile development--Protection by plant-cover retards the removal of surface soil and gives time for the soil-forming processes to work to completion. Without vegetation's aid to weathering and to the chemical and biological processes of soil-formation, mature soils could not develop. Together, mature soil and vegetation reduce runoff. Stems, roots, and plant-litter retard surface flow, and, from the leaves, moisture is returned to the air by transpiration.

Climate, working through its control of the plant-cover, produces great regional variations in mature soils. In humid and sub-humid lands, where the surface is normally well covered with vegetation and vegetal litter, deep soil-profiles can form. In regions too arid to have adequate plant-protection, gullying, sheet-washing, and wind-erosion have always been active. Without mantling vegetation, there can be no soil-material on slopes steeper than the angle of repose, and even on more gently sloping land the products of weathering wash or blow away almost as quickly as they are formed.

Changes in erosion brought about by man's use of the land--Normal soil-development, normal erosion, normal balance of the several processes of denudation, and even normal sculpturing of the surface of humid lands, then, can take place only with the presence of a normal vegetal cover. Man, by removing the natural vegetation, has destroyed the balance of all of these relations. In clearing the forests and baring the land for cultivation, man has added his destructive powers to those of nature. Runoff has been greatly increased, both in rate and amount and, as a result, streams now flow less regularly, their load is carried fitfully, and their floods reach higher crests.

Changes wrought by man have increased sheet-erosion, rilling, gullying, and wind-erosion. These processes truly have been accelerated. The natural downhill creep of the soil, however, now is of smaller relative consequence than under natural conditions. It is probably smaller in absolute value, too, owing to the general reduction in ground-moisture.

Recent work on geomorphology of accelerated erosion--Recent studies by the Climatic and Physiographic Division of the United States Soil Conservation Service have increased our knowledge, not only of the dynamics of accelerated erosion, but of the whole relationship of the present accelerated cutting to erosion in the past. Field-work in the Piedmont of South Carolina, for example, has helped to explain the rapid erosion of abandoned lands and has outlined the life-cycle of the characteristic deep, caving-walled, Piedmont gully.

On agricultural lands, the periodic reworking of the surface soil helps materially to prevent concentrated erosion. Soil is still removed by sheet-erosion and rilling, but listing and cultivating tend to equalize surface irregularities and prevent gully formation. When land is abandoned and this equalizing process ceases, rills persist and rapidly grow to gully size.

The direct results of rainfall and runoff in producing sheet-erosion in the Piedmont can readily be seen in micro-geomorphic forms, such as miniature soil-pillars capped by stones, leaves, twigs, or miscellaneous matter. Pillars almost four inches high, protected only by a tight covering of lichen, show strikingly the protection offered by even a thin layer of organic material.

As rills develop and deepen, stones left by the sheet-washing of the finer soil-components tend to migrate down the barren slopes and accumulate in the beds of the rills, forcing the channels to move laterally into less resistant material. Only exceptionally heavy rains can remove the stones from the smaller channels.

On the slopes between rills, frost and lesser daily temperature-changes loosen the surface layer of bare soil and prepare it for easy removal. Unpublished data from sloping test-plots show that by the action of needle-ice or spew-frost in one moderate freeze and thaw, more than 18 pounds of soil per 100 square feet of surface may be loosened and allowed to slide or fall to the base of the slope.

The thick fluffy crumb-mulch that forms on bare surfaces of the B-horizons on many of the Piedmont soils is found to offer protection against light rains, but is removed by heavier precipitation. Measurements of the loss of crumb-mulch from small gently sloping plots of Cecil, Davidson, Lockhart, and Georgeville soils show rapid removal directly correlated with the volume and intensity of rainfall. Iron markers 3/8 inch in diameter driven two feet into the ground on these plots reveal the carrying away of an average of 1/4 to 3/4 inch per year, with a maximum of more than two inches in as many months at individual markers. Other investigations of sheet-erosion and rilling are now in progress.

Where erosion goes unchecked, the pattern of small drainage-ways soon becomes better integrated, and the larger rills develop into gullies. The life-cycle of the Piedmont gully, underlain by a weak saprolite, or zone of rotten rock, has been traced through four stages by Ireland, Sharpe, and Eargle [4]. These gullies migrate headward up the channel, and several stages may be represented simultaneously in a single gully.

First is the stage of downcutting, when the gully is limited to the A- and B-horizons. Water-scour, loss of material from gully walls by frost-action, and washing down of crumb-mulch mark this stage. It ends with the development of pot-holes, penetrating into the saprolite. Although in some parts of the Piedmont the tight B-horizon type of material reaches to a depth of ten or more feet, and gullies can be large even in this stage, growth in stage one is relatively slow. This is the time to stop gullies!

Once cutting has penetrated the base of the B-horizon, marking the start of stage two, gully growth takes a tremendous spurt. Downward cutting gives way to rapid enlargement by a headward migrating knickpoint or overfall. This is the stage of fastest enlargement and maximum size and depth of gullies. Seeping of ground-water from the gully head, and back trickling of flow down the head wall beneath the protruding lip remove the weak material low on the gully wall, and caving of the resistant lip results.

Maximum rate of gully growth during this second stage depends on the alternation of two types of storms. Most of the caving of gully walls follows prolonged widespread storms of low intensity, the drizzling rains or "'tater soakers" usually associated with the passing of a warm

front. This type of storm, characteristic of the winter months, tends to choke the gully channel. Side walls of gullies retreat, and may reach a low enough angle, so that stabilizing vegetation can gain a foothold. Thus, a gully generally shows its most benign aspect in the late winter and early spring, and this would be the optimum time to divert water, and undertake to establish vegetation on the walls.

Few of the drizzling winter rains cause much removal of material from the gully channel. That is done by the cold-front rain, characteristic of summer months, by summer thunder-showers, and by occasional tropical cyclones. Periodic observations of selected Piedmont gullies showed that material falling from gully walls in January lay almost undisturbed till well into the summer and, where caving had been especially heavy, the material was not completely removed for more than a year [4].

Following the rapid deepening of the gully in stage two, enlargement goes on much more slowly. If the gully channel is graded to a local base-level, the walls may in time slope back to a normal angle of repose. This is the third or healing stage and, where the cycle is complete, is followed by the final stage, stabilization, marked by the covering of the gully walls with vegetation, and in some places by the silting of the gully until it is partially or completely filled. Use of this knowledge of the gully-cycle in the planning of gully-control measures will make for economy of effort and provide more lasting results.

Basic research on the geomorphic background of soil-development and accelerated erosion in the Piedmont shows that the region has had a complex history of cutting and refilling. It has long been known that many of the Piedmont valleys contained feet, or even tens of feet, of fill, largely the result of deposition from overbank flooding. The common presence of a layer of peaty material, containing leaves, cones, and large logs, at a depth of 5 to 20 feet beneath apparently normal mature soils of upland hollows has only recently been recognized. Detailed investigations by Eargle, briefly reported in Science [2], included the boring of more than 800 auger holes and showed the existence of buried organic matter in many places where its presence had not been suspected.

Even the land form in which these deposits characteristically are found has received little attention in this country. It is described by German geomorphologists as the Delle [9] and gradually is becoming known here as the "dale" [8]. The typical dale is a broad rounded depression, the sides and bottom of which merge without any abrupt angle. Many dales are now cut by longitudinal gully channels, but they are believed to have been channelless under natural erosion-conditions. Analysis of the landscape of the Piedmont Upland shows that dales make up a large part of the area. In little-dissected sections, the surface of the dale may have a relief of only a few feet. Elsewhere the difference in elevation from bottom to rim may be 50 feet or more.

The large number of filled valleys and dales in the Piedmont indicates that at one time, during or before the Pleistocene, the surface of the land was much more rugged than it is now. Following this period of greater relief, the filling or partial filling of the valleys, accompanied by erosion and mass-movement of material from the hills and ridges, produced a much subdued topography. Immediately before the introduction of agriculture, the surface of the Piedmont was very gently undulating and broad low ridges alternated with deeply filled dales. Trenching by recent accelerated erosion has exposed in places the considerable deptn of pre-agricultural fill.

The finding of deep fills in many areas of the Piedmont introduces complications into the mapping and interpretation of Piedmont soils. It has long been believed that the mature soils of the Piedmont are derived from underlying sedentary materials and that soil series correlate closely with specific rock types. Cecil soils, for example, are considered to be derived from a granite, granite gneiss, or crystalline schist parent rock. Soils with typical Cecil profile are now found to lie not only on sedentary materials of these types but on fills, which in turn may overlie an altogether different type of bedrock.

Sections constructed from series of borings across dales show that on the upper slopes of a dale the soil is usually relatively thin. A three-foot auger may be sufficient to reach saprolite. Farther down the slope, the layer of soil and soil-material is thicker, and in the center of the dale may approach 30 feet. The characteristic profile in the dale bottom shows mature soil with the B-horizon grading downward into a clayey B-like zone. Below this are several inches to several feet of peaty material, which in most places lie on a thin layer of quartz gravel, resting in turn on saprolite. From the distribution and texture of the deeper parts of these fills, it appears that both slope-washing and soil-creep have contributed to their

formation. Some of the soil-material is definitely laminated and was deposited from flowing water. Other parts of the material are massive and appear to be the product of soil-creep.

On the side slopes of the dale, the organic layer normally is missing, but a layer of quartz fragments beneath the soil-material marks the line between undisturbed material below, which retains rock-structure, and moved material above, which does not. This line of rock-fragments or stones is one of the most important keys to the location of deep soil-masses. It was noticed as early as 1882 by Kerr [5], but few workers have followed his interpretation or paid much attention to the phenomenon since that time.

The significance of this irregular layer was recognized during field-work of the Soil Conservation Service in the Piedmont in 1936 and the term "stone-line" was applied to it [10, 11, 4]. Further studies have shown, more and more clearly, the importance of this line. Differences in erodibility of adjoining areas on the same soil-series in relatively similar topographic position have been explained for the first time when physiographers have been able to determine that, in the more easily eroded area the soil directly overlay the parent-rock material, whereas in the more resistant area the soil-mass was underlain by a stone-line, or stone-layer, indicating that lateral migration or transportation had taken place. Stone-lines are most apparent in regions of granitic or gneissic rock deeply weathered to a friable saprolite, but cut by quartz veins that resist weathering.

The applications of these Piedmont geomorphic studies to conservation work are fourfold. They give a more complete understanding of soil-genesis in the Piedmont, and explain the causes of some of the local differences in soil-erosion. Second, the regular arrangement of shallow and deep soils within a dale or within several dales in a small headwater drainage indicates the necessity of using a physiographic unit as the basis for erosion-control and conservation operations. The concept of the unit-drainage, the small headwater basin of the Piedmont streams, is being developed as an aid in the preparation of coordinated farm plans. Third, an understanding of the physiographic history of the region and a knowledge of the common presence of deep soils make it feasible to utilize the deepest soils for construction of waterways and other drainage-structures, thereby assuring against rapid cutting out in case of excessive storm-runoff, as might occur on a shallower soil underlain by deep saprolite. Appreciation of the physiographic pattern and history makes it possible to locate the deep soil-bodies of an area with less expenditure of time or effort. Fourth, the presence of former deep valleys indicates that accelerated erosion can take place without the aid of man, and that periods of excessive cutting can, by moderate change of conditions, be halted and replaced by periods of alluviation.

Evidence of former deeper erosion is by no means limited to the Piedmont. Unpublished studies by Ireland on the Caddo Canyon area of west-central Oklahoma show a great depth of fill of probable Tertiary age in old rock-cut canyons. Recutting of the canyons by removal of the fill has been going on since before the coming of agriculture to the area. Since 1914, one of these drainageways has been enlarged from a channel approximately ten feet deep, crossed by a small wooden bridge, to a canyon 55 feet deep that had to be bridged by a 75-foot steel truss. A number of canyons of this sort have already been reexcavated in Caddo and Canadian counties, and it is probable that they are part of a system that extends beneath a considerably larger area. The importance of preventing further uncovering of the old rock canyons is obvious.

Bryan [1], Hack [3], the Soil Conservation Service [12], and others have shown that in the valleys of the Southwest many channels have been cut and partly or completely refilled prior to the present acceleration of erosion. Regardless of their cause, these older alternations of cutting and filling show that in the Southwest, as in more humid parts of the country, the geologic norm was highly variable.

Conclusions--Filled channels in many parts of the country show that under natural conditions the land was far from free of local or occasional acceleration of erosion. The change from pre-settlement normal erosion to post-settlement conditions of accelerated erosion was, in part, an increase in the proportion of the land subject to accelerated erosion, in part an increase in the degree of acceleration, and in part a modification in the balance of the processes of erosion and denudation. On the veins of the leaflike normal drainage network, erosion was accelerated. On the intervein areas, there was a marked change in process, rather than simple acceleration. Mass-wastage by soil-creep, earth-flow, and other mass-movement processes gave way, in part, to the removal of the soil by slope-washing or sheet-erosion, which logically resulted in the development of rills and gullies.

Consciously or unconsciously, geomorphologists have always studied accelerated as well as normal erosion. Concentration on accelerated erosion, however, has opened a new and promising

field of geomorphic research, in which results of considerable economic worth are being obtained. Only a beginning has been made, but already it is becoming plain that detailed studies of the dynamics and land forms of accelerated erosion will help to clarify principles of the geomorphology of normal erosion as well.

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